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AFFTC, TR 60-53

PUMPING HYDRAZINE
WITH A
TURBOPUMP

CONTRACT NO. AF33(616)-6774

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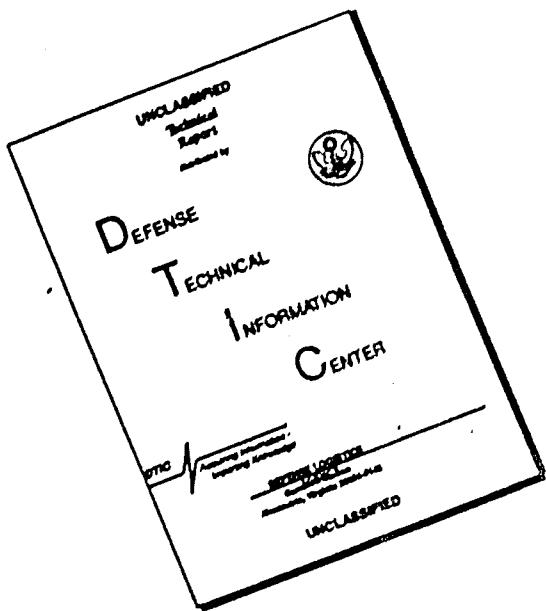
L. C. Rose

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STRATEGY

This report covers a test program conducted by Thompson Ramo Wooldridge to prove the feasibility of pumping hydrazine with a turbopump. The results show that vapor lock, cavitation, and dead ending can be tolerated with hydrazine. Careful attention must be paid to the temperature rise which results from dead ending or flow stoppage due to vapor lock, however the rise in the case of the pump tested was gradual enough to allow corrective action by an observer. Materials used in the wide range of conditions of operation for a total shaft stood up well under 35 minutes and 33 seconds.

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1.0 INTRODUCTION

This is the final report to Air Force Flight Test Center, Edwards Air Force Base, California. The report covers work done from June 1959 to April 1960. The primary purpose of the program was to determine whether any undue or unexpected problems might turn up in pumping hydrazine under a wide range of conditions.

1.1 Objectives

Main objectives were to ascertain the effects of cavitation, vapor lock, and dead ending, plus mechanical problems when pumping anhydrous hydrazine. Overall pump and turbine efficiency were not taken into account.

2.0 APPARATUS

2.1 Turbopump

Since this program was in essence a feasibility study, a standard production water injection turbopump, P/N 118600, was selected for the test phase. Seal material and mechanical features were modified to be compatible with hydrazine. The pump performance parameters pumping water are as follows:

Pump Speed - 22,000 rpm
Flow - 80 gpm
Head Rise - 300 psi

The performance characteristics for hydrazine should be approximately the same as those for water due to physical similarities between the two fluids. Figure 1 shows the assembly of the modified hydrazine pump and Figure 2 shows the seal assembly.

2.2 Turbine

The turbine is a partial admission axial flow impulse type. Air at 600 °F is used to operate the turbine in its normal application, but decomposed hydrazine cooled to 400 °F was used for these tests. Inlet pressures varied from 50 psig to 110 psig. No attempt was made to optimize or evaluate the turbine performance.

2.3 Pump

The pump has a double shrouded impeller with labyrinth seals to restrict recirculation. Pressure balance holes are provided in the impeller. The discharge section is uniform around the impeller and leads into an annular section which contains diffuser vanes parallel to the axis of rotation.

2.4 Bearings

The bearings used are ABEC angular contact 104 Class 3. They are pre-loaded to insure a constant contact angle with an end play of from .004 to .006 inches. This bearing combination was operated up to 24,000 rpm. Lubricant type AN-09 grade 10-10 was used to supply lubrication to the pump bearings. This grease was not compatible with hydrazine. No attempt was made to procure a grease that was compatible with hydrazine inasmuch as double sealing was provided to prevent contact.

2.5 Seals

Seal design, both labyrinth and face type, represented the major design problem. Glass filled teflon was selected for the labyrinth wear rings. Due to the cold flow properties of the teflon under pressure it was retained with a split clamping ring. Mating labyrinth rings made of 304 stainless steel were pressed on the impeller. The face seal consisted of an aluminum oxide coated stationary seal mated with a rotating ring also coated with aluminum oxide.

2.6 Material Selection

All parts of the pump that came in contact with hydrazine were changed to type 304 stainless steel, aluminum or teflon, depending on the conditions of service to which the material would be subjected.

2.7 Test Stand

A gas generator using hydrazine as the fuel was used to drive the turbo-pump. A heat exchanger cooled the exhaust gases to 400 °F. Inlet pressure to the pump was supplied by nitrogen pressure regulated from a remote controlled pressure regulator. Figure 3 is a schematic of the test stand set-up.

2.8 Instrumentation

Direct writing oscilloscopes in conjunction with strain gauge type transducers were used to record pressures. Direct writing multiple point recorders with thermocouples were used to record temperatures. Both venturi type flow tube and turbine type flow pickups with direct writing oscilloscopes were used for recording flows.

3.0 TEST PROCEDURE

The test program was designed to determine the effects of the following factors on pump performance and life:

1. Fluid inlet temperatures.
2. Fluid inlet pressures.
3. Pump speed and net positive suction head.
4. Vapor lock.
5. Cavitation.

3.1 Fluid Inlet Temperature

No attempt was made to vary the ambient fluid inlet temperature, therefore, all tests were run at approximately 80 °F. Local temperature variations were effected by manipulation of inlet and outlet valves. Fluid temperature readings were taken at 2-inches upstream of the pump inlet flange, and 3/4 inches downstream of the discharge flange.

3.2 Fluid Inlet Pressure

The fluid inlet pressure was maintained at approximately 85 psig throughout the runs to give good suction conditions to the pump. Cavitation and vapor lock tests were made by closing the valve to the suction side of the pump. Fluid pressure readings were taken 2-inches upstream of the pump inlet flange and 2-1/4 inches downstream of the discharge flange.

3.3 Pump Speed and Net Positive Suction Head

The pump was run at a maximum speed of 18,000 rpm throughout all the runs. An attempt was made to determine the minimum NPSH by observing pump performance during fall off of inlet pressure after closing the pump inlet valve. An inspection of the pump parts was made after the tests were run to determine the effects of the reduced inlet pressure on the impeller and seals.

3.4 Vapor Lock

The vapor lock test was run concurrent with the net positive suction head tests. In order to first produce cavitation and subsequently to vapor lock the pump, the inlet pressure was gradually reduced by slowly closing the inlet valve. Oscillograph traces of the results were made to determine if a vapor lock condition had been reached. A visual inspection of the pump parts after the run determined the effect of vapor lock on the pump.

3.5 Cavitation

Cavitation tests were run concurrent with the NPSH and vapor lock tests. The results of these tests were evaluated from the oscillograph traces.

3.6 Dead Ending

The pump was dead ended by closing the pump discharge valve for a short period of time. The temperature rise across the pump was observed during this operation.

4.0 DISCUSSION OF RESULTS

4.1 Fluid Inlet Temperature

The fluid inlet temperature remained at 80 °F throughout the tests except for the "dead ended" test. Figure 4 is an oscillograph trace showing the

results of closing the discharge valve to effect "dead ending" of the pump. Figure 5 is a record from a multiple point recorder showing the pump inlet and discharge fluid temperatures. A temperature variation of 4 °F to 13 °F exists between the two readings except in the case where the discharge valve was closed (note Figure 4). The discharge temperature rose to 216 °F, giving a temperature rise of 138 °F across the pump. There was a total running time of 55 minutes and 33 seconds on the modified pump with hydrazine.

4.2 Fluid Inlet Pressure

The fluid inlet pressure remained at 85 psig throughout the runs except when cavitation and vapor lock tests were run. Results of these tests are shown in Figure 6.

4.3 Pump Speed and Net Positive Suction Head

As stated in Section 1.1, the main goal was to establish the ability to pump hydrazine with a turbine driven centrifugal pump. Figure 7 is a plot of head rise as a function of flow at a speed of 16,000 rpm. The maximum speed was 18,000 rpm. No indication of loss in pump performance or damage to pump parts due to speed was encountered. The minimum NPSH was not determined over the entire flow range. At one point, shown by Figure 6, with the inlet valve just opened, a NPSH of 10.41 feet was reached. At a speed of 14,400 rpm and 40.5 gpm flow, this corresponds to a suction specific speed of 15,800 rpm.

4.4 Vapor lock

A vapor lock condition was effected by closing of the inlet valve. However, an evaluation of conditions below a pressure of 5 psia was not possible due to limitation of the pressure transducer being used to sense pressure. No temperature rise was observed at the pump inlet and discharge. No adverse effects on the impeller or seal was observed, and more important there were no apparent adverse effects on the hydrazine.

4.5 Cavitation

Cavitation in this test was induced by shutting off the pump inlet as shown by Figure 6. This produced a drop in flow and pressure which induced cavitation. This test proved the ability of the pump to cavitate without causing explosive decomposition of the hydrazine.

4.6 Seals

During the running time of 55 minutes and 33 seconds, there was a total of four cubic centimeters leakage. The aluminum oxide coated rubbing surface showed negligible wear. The labyrinth seals showed no wear. Figure 8 is a photograph of the pump hardware after testing. No wear was apparent in the pump parts. Since the seals represent the major design changes, both from the mechanical arrangement and material compatibility standpoint, the hardware design criteria has been well established.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Fluid Inlet Temperature

Although the fluid inlet temperature was not varied, the higher inlet temperature may have an effect on the pump performance. Therefore, further tests should be run by varying the fluid inlet temperature over a given range to determine effect of pump corrosion and limitation of pump performance with fluid temperature.

5.2 Fluid Inlet Pressure

Explosive decomposition of hydrazine did not occur at low inlet pressures, however, further tests at reduced inlet pressures should be run to determine corrosion effect of prolonged running on the impeller and seals.

5.3 Pump Speed and NPSH

Tests run at 18,000 rpm proved the ability of the pump to pump hydrazine. Tests should be run at 20,000 and 22,000 rpm to give an evaluation of the turbopump at these speeds. Although tests indicate that the minimum NPSH is 10.41 feet, these tests should be repeated with flow indicators which can record the minimum values of flow that would be encountered for this test.

5.4 Vapor Lock

Although the pump was vapor locked without harm, temperature probes were not located to adequately reflect changes in temperature within the pump itself. Therefore inlet and discharge thermocouples should be changed to a location of closer proximity to the impeller and scroll to indicate truer indication of temperature variation in the pump when a condition of vapor lock occurs. To prevent the auto-decomposition of hydrazine, a temperature sensing emergency shutdown device should be required in an actual application.

5.5 Cavitation

Although cavitation appeared to produce no damaging effects on the pump or hydrazine, further tests for prolonged periods should be made.

5.6 Seals

In general, the seal problem has been resolved, although specific pump requirements, i.e., flow, discharge pressure, and speed will require adequate seal component testing to prove out a specific design. Aluminum oxide which was used as the face material has long been considered compatible with hydrazine because of the excellent storage history of hydrazine in aluminum containers. In addition, Mathieson Chemical Corporation states in their published book "Hydrazine" by Charles C. Clark, that "aluminum oxide has a stabilizing effect on hydrazine and tends to supply a buffering action to the unstable hydrazine ion, $N_2H_3^+$ ".

6.0 SUMMARY OF RESULTS

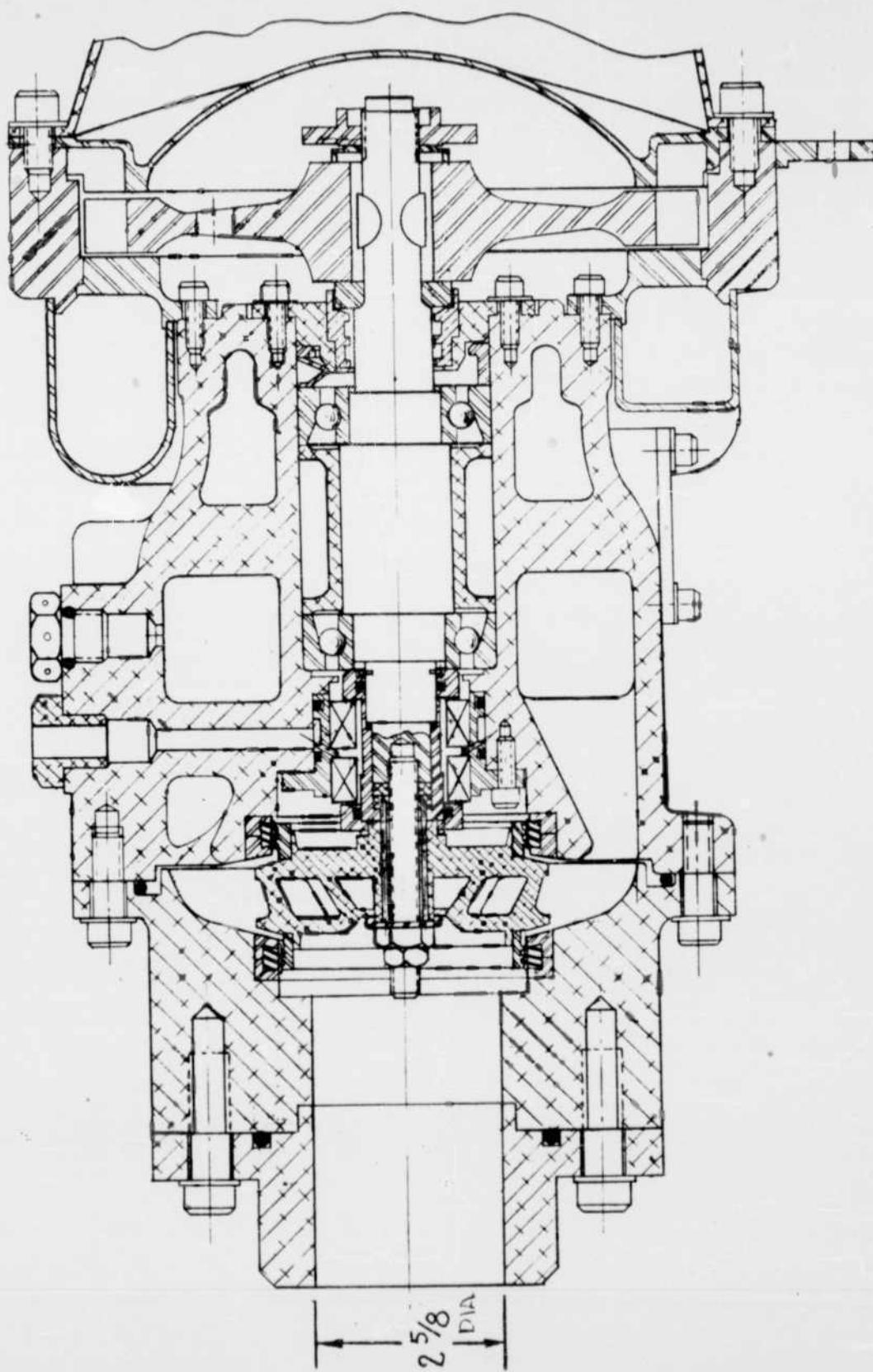
The tests show conclusively that hydrazine can be pumped with a centrifugal pump under a wide range of conditions including dead ending and vapor lock without auto-decomposition of hydrazine or undue wear on materials. The materials used were compatible and stood up well for a time duration of 55 minutes and 33 seconds.

No major design problem appears to exist in this turbopump. The tests prove that the unit will pump hydrazine with minute seal leakage (Four cubic centimeters per hour in this case). The dead ending of a pump should be monitored by a temperature sensing emergency shutdown or by-pass device.

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TURBINE DRIVEN CENTRIFUGAL HYDRAZINE PUMP

FIGURE 1

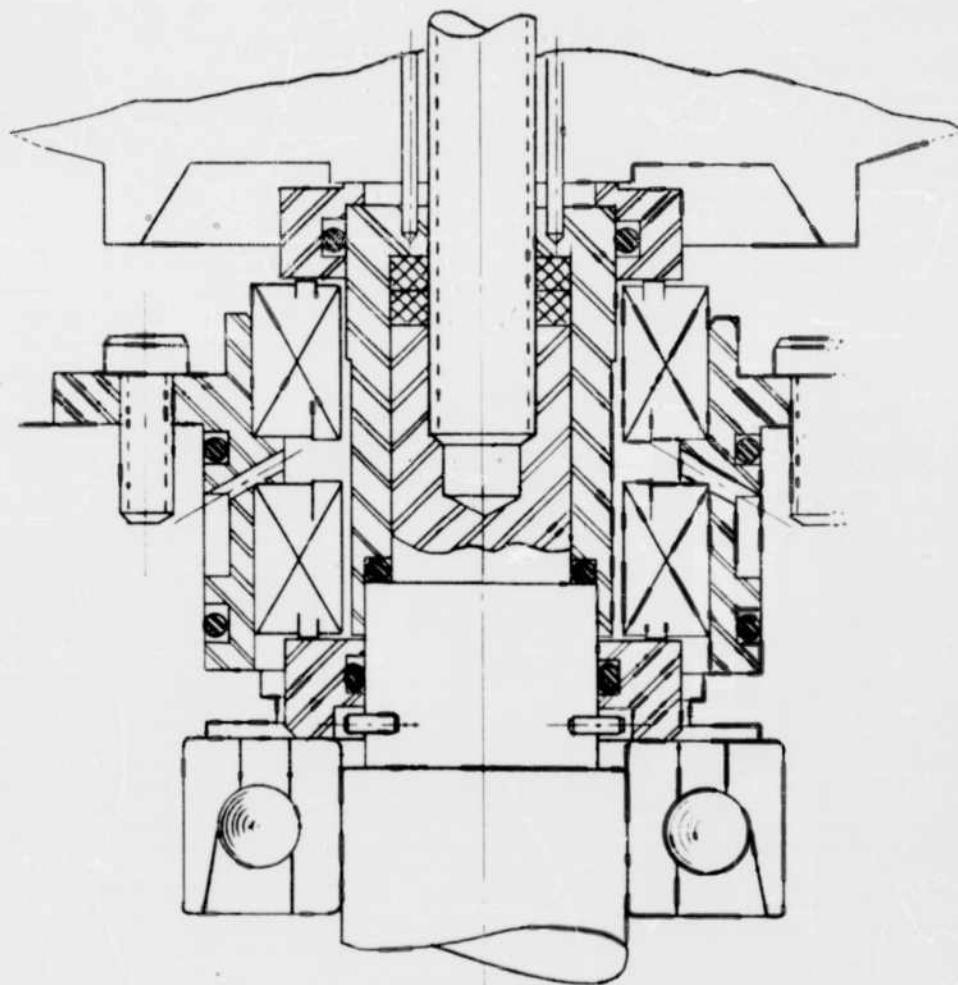
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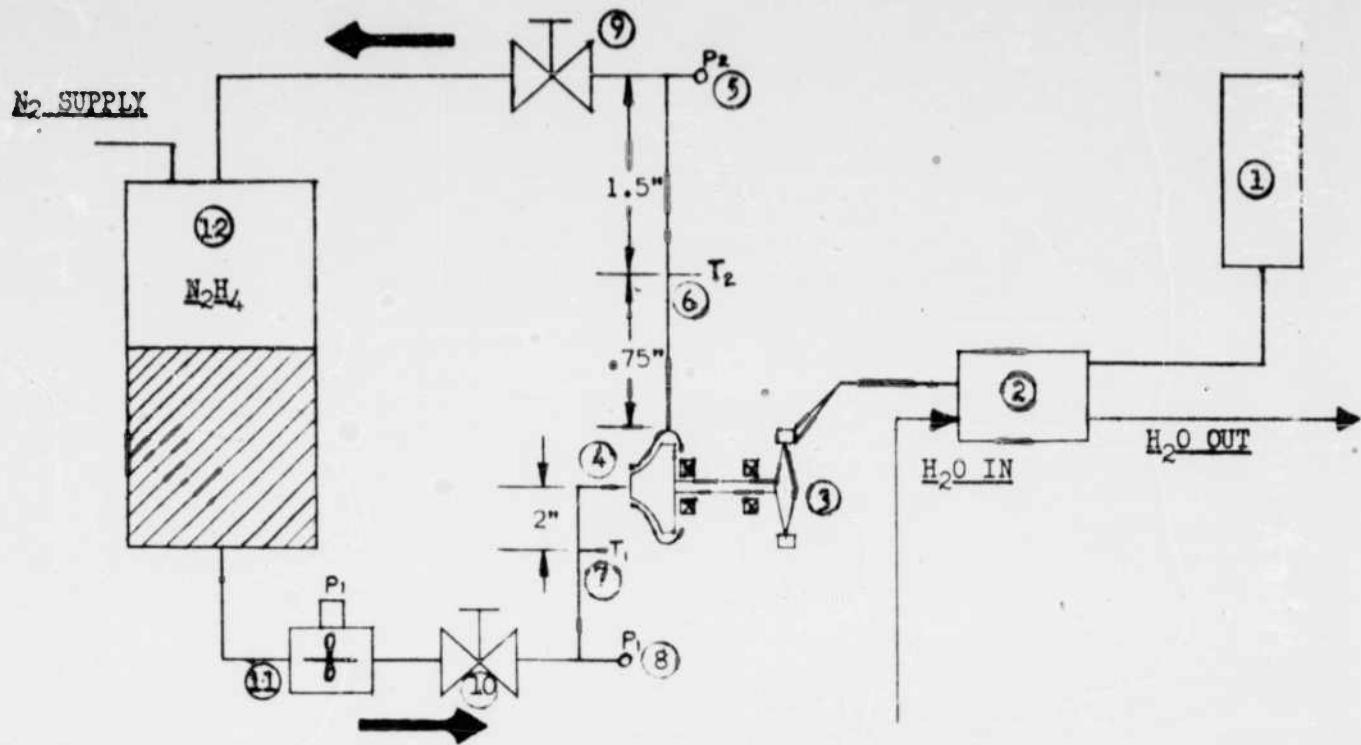
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FIGURE 2

SEAL ASSEMBLY - HYDRAZINE PUMP





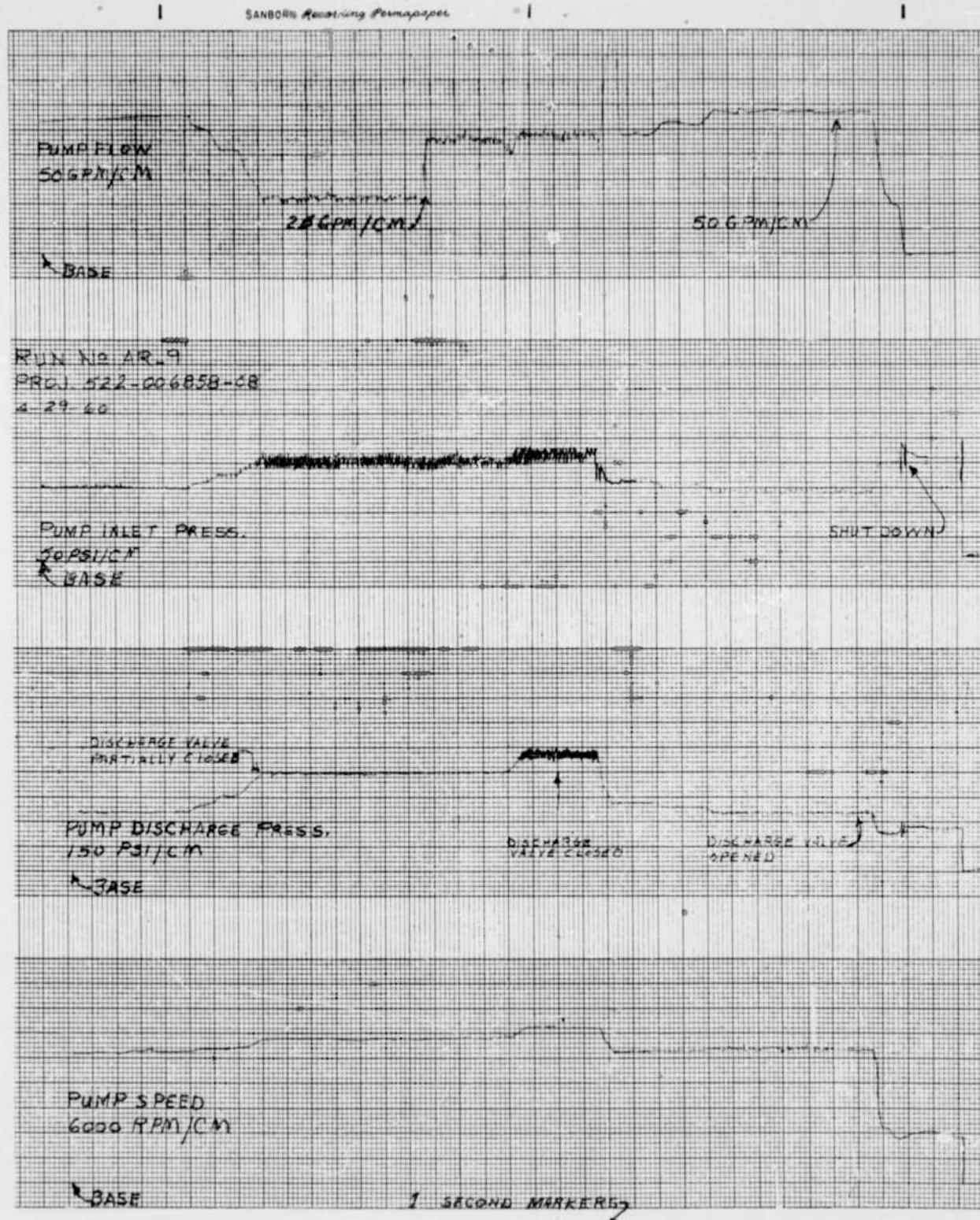
- (1) HOT GAS GENERATOR (HYDRAZINE)
- (2) HEAT EXCHANGER
- (3) PUMP TURBINE
- (4) PUMP (HYDRAZINE)
- (5) DISCHARGE PRESSURE TAP
- (6) DISCHARGE TEMPERATURE
- (7) INLET TEMPERATURE
- (8) INLET PRESSURE TAP
- (9) DISCHARGE THROTTLING VALVE
- (10) INLET THROTTLING VALVE
- (11) FLOW METER
- (12) HYDRAZINE RESERVOIR

FLOW SCHEMATIC - HYDRAZINE PUMP

FIGURE 3

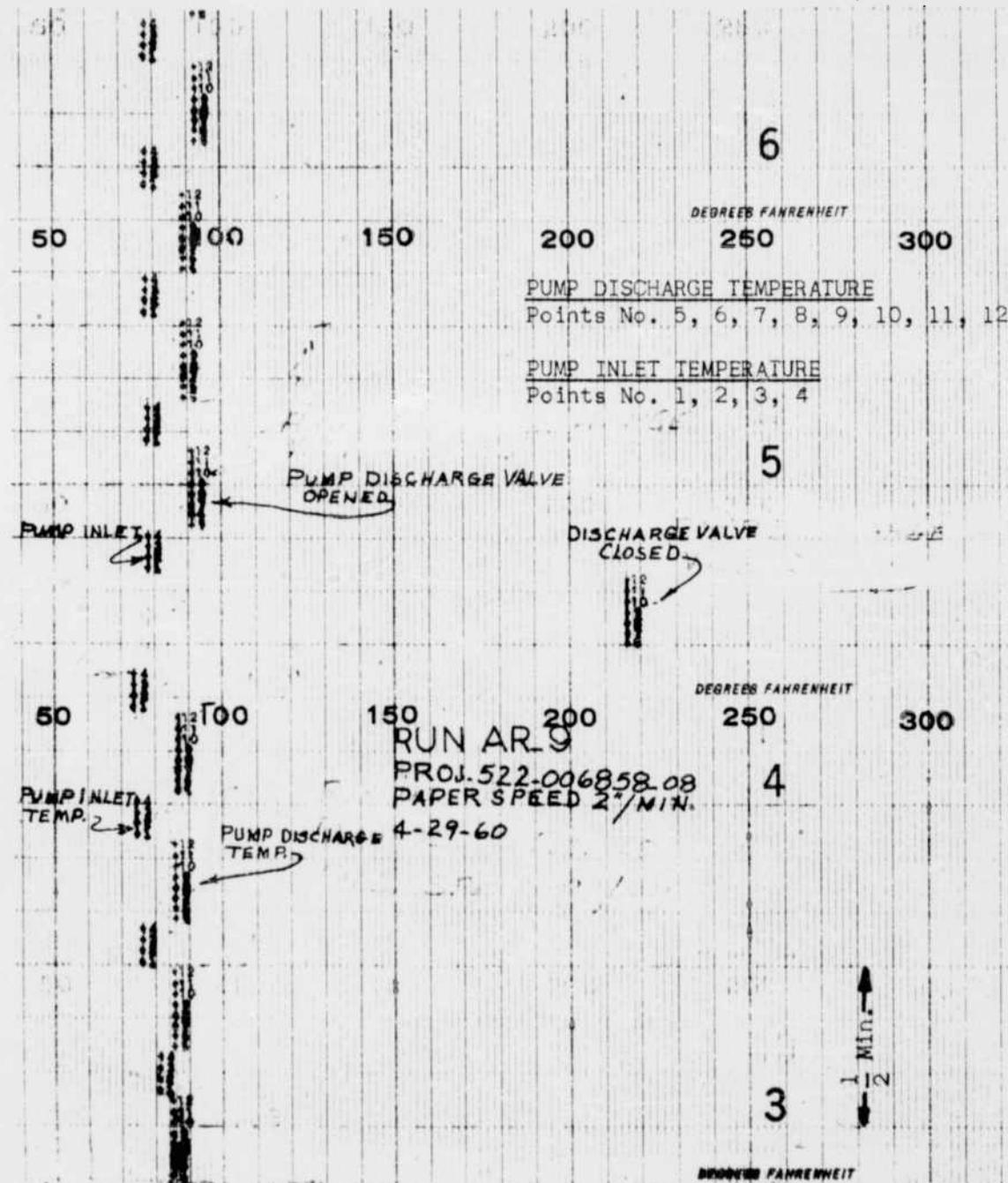
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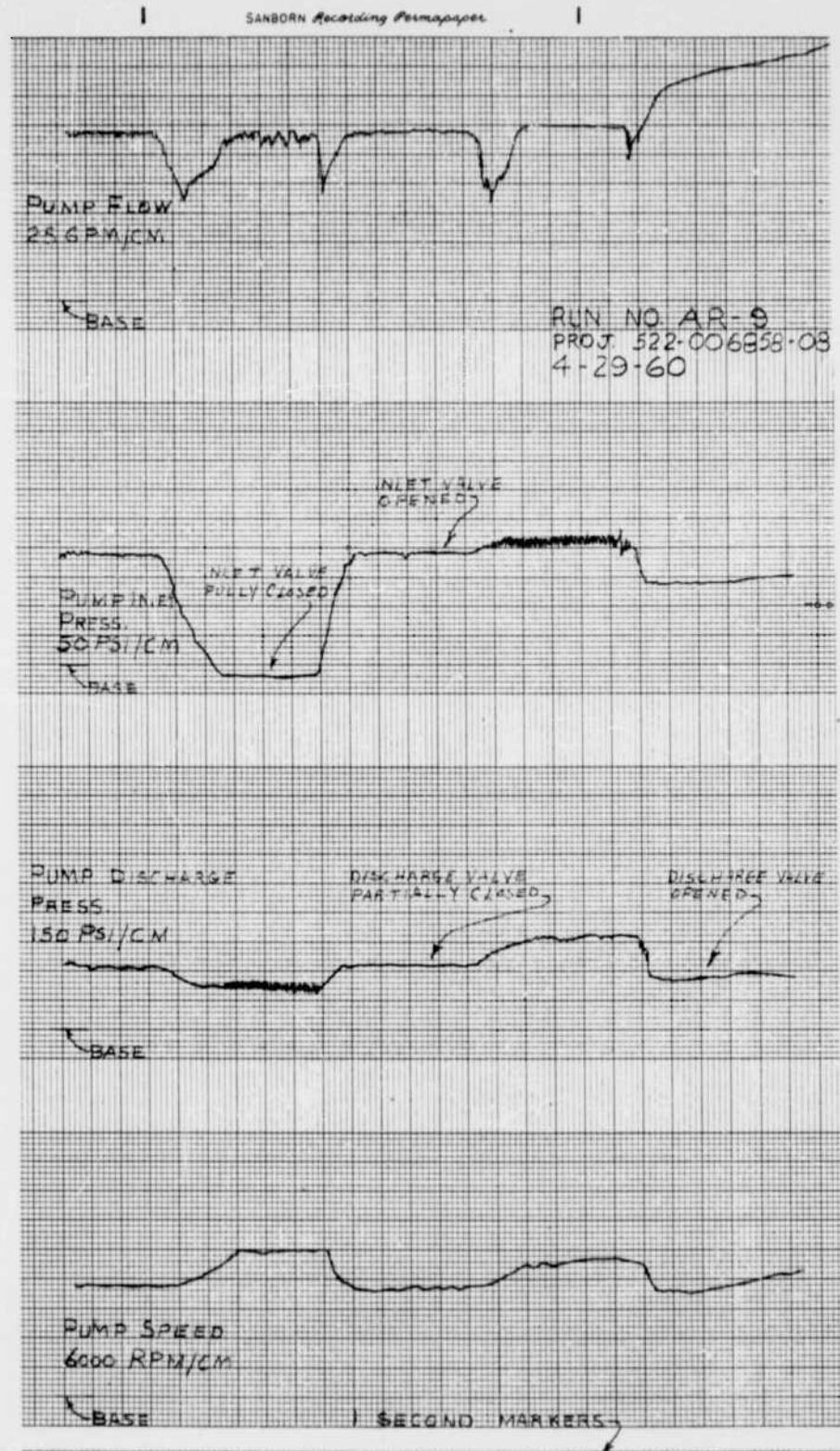


EFFECTS OF CLOSING OFF THE DISCHARGE VALVE

FIGURE 4

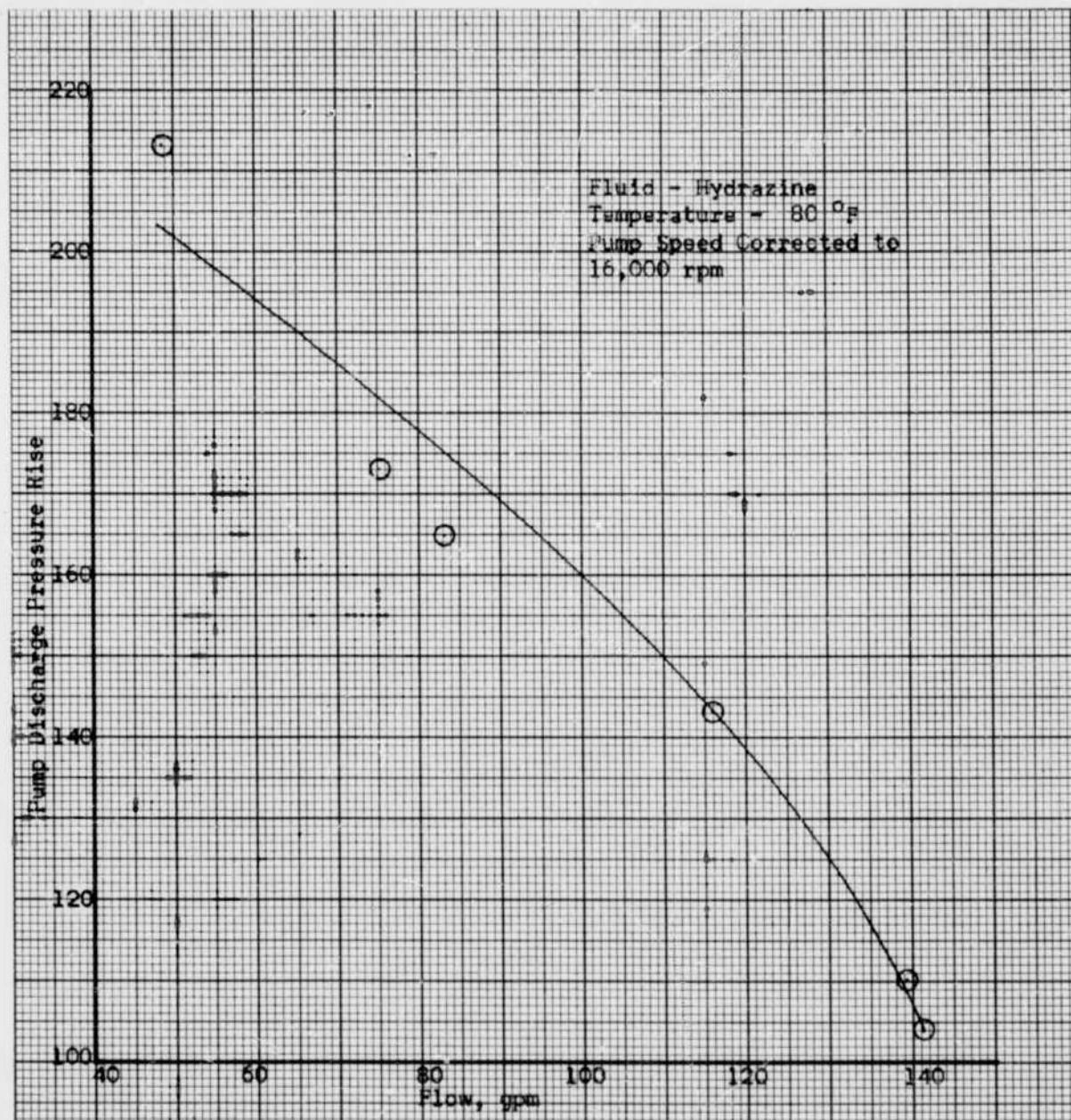


TEMPERATURE RECORDER TRACE DURING DEAD ENDING OF PUMP FIGURE 5



EFFECTS OF CLOSING OFF THE INLET VALVE

FIGURE 6

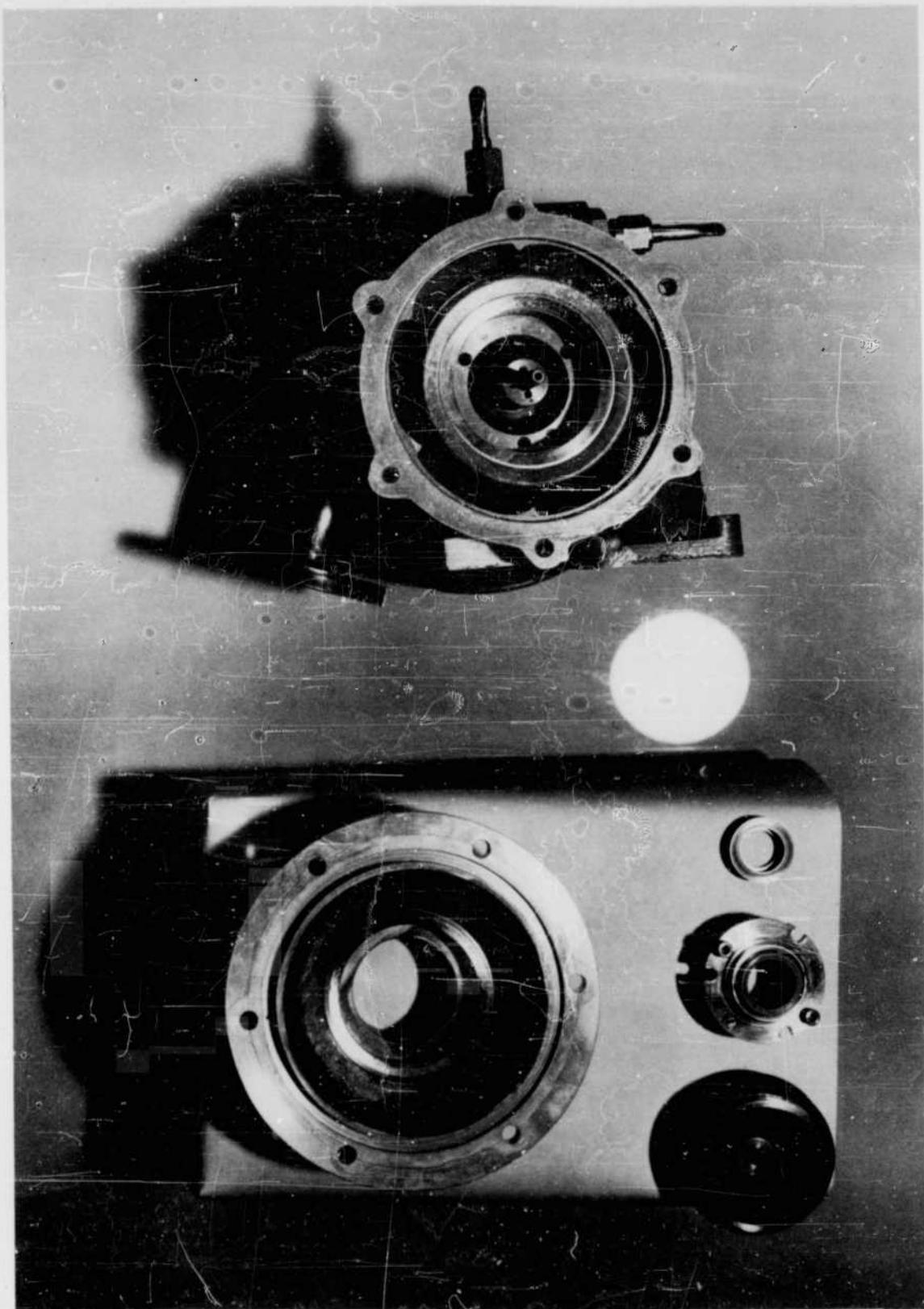


HYDRAZINE TURBOPUMP HEAD RISE VERSUS FLOW

FIGURE 7

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HYDRAZINE PUMP PARTS AFTER TESTING

FIGURE 8